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ON THE MEASUREMENT OF EQUIVALENT FOCAL LENGTH OF TELESCOPE LENSES

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ABSTRACT. A biprism method for rapid measurement of equivalent focal length of telescope lenses is described It has been shown that precise measurement of focal length is possible even if the biprism is afflicted with small spherical refracting power. The accuracy obtained by the method was found to be within about ± 3 per cent

INTRODUCTION

For the determination of equivalent focal length (e f l) of a lens or lens combination, Indian Standards Specifications (IS 988 · 1959) laid nodal point, Newton's, magnification and focometer methods. The tolerance for nominal focal length is specified as within ± 5 per cent unless otherwise stated

Employing a biprism with zero spherical refracting power, Darling (1962) has outlined a method for rapid determination of the e.f l. of flat field lenses It was reported that this method permitted a quick check on e.f.l. value of a given lens obtained with the optical bench.

Because of the inherent simplicity and rapidity of Darling's method, an investigation was taken up at this Organisation to ascertain whether it can also be incorporated for e.f.l. measurement in Indian Standards Specifications. The approach adopted had to be, however, a little modified as the available biprism possessed spherical refracting power of $+0.25$ diopters.

THEORY

A collimated beam is split with the help of a transmitting biprism, afflicted with spherical refracting power, into two nearly parallel beams inclined at a small angle θ. On traversing through the lens T under test, two images laterally separated by a distance, d, are formed. It can easily be deduced that focal length, f, of T is represented by the equation :

$$f \pm e = Kd \qquad \ldots \quad \text{(i)}$$

where e is the distance between the image and true focal plane of T and $K \simeq \cot \theta$. Since d, e can be experimentally measured, the constant K is first evaluated, employing lenses of known focal length, and using equation (i) above. The procedure can then be repeated for determining e.f.l. of unknown lens.

EXPERIMENTAL

The experimental arrangement used is illustrated in Fig. 1 It was set up on an optical bench, vernier constant 0.05 mm The slit S was illuminated with

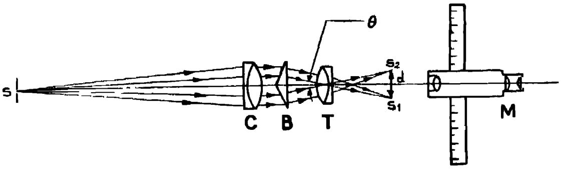

Fig. 1. Experimental set-up.

filtered green light from an incandescent lamp and collimated with the help of an achromatic doublet lens, C, of 5 cm aperture and 60 cm focal length. The distance between the two slit images S_1 and S_2 formed by T was measured with the help of a travelling microscope M, least count 0 01 mm. e was measured on the bench by sliding the carriage carrying M.

It was observed that with the available biprism the two slit images did not appear in focus simultaneously indicating thereby that the biprism possessed non-symmetrical refracting power This observation introduced uncertainties in measurements and hence the following two different procedures were adopted for evaluation of d, e and the results compared

In procedure I, the optimum position when the two slit images appear in best focus simultaneously is located on the optical bench, and d, e measured

In procedure II, without B, the best focus position X_0 for the slit image is first located on the optical bench and the image centred on the cross section of an eyepiece graticule B is now introduced and the two slit images are focused in succession moving the carriage carrying M, noting their positions X_1, X_2 and recording from the centre on the ocular micrometer the distances d_1 and d_2 of slit images. 'd' was taken as $\overline{d_1+d_2}$ and 'e' as $\overline{\frac{X_1+X_2}{2}}-X_0$.

In both the above cases, measurements were made on same lenses, repeating individual observations five times. As a counter check, the nominal focal length, f_n, for each lens was also determined independently, with the help of an improvised focometer.

RESULTS AND DISCUSSION

Following procedures I and II outlined above, the results obtained are given in Tables I and II respectively The plot between d *vs* (f_n-e) is a straight line passing through origin (Fig 2). The correlation coefficient is 0.985 On statistical analysis K comes out as 173.3 ± 1.6, which value was used in equation (i) above for computing 'f' by both procedures.

TABLE I

d, e and K results as obtained by two procedures*

Lens No	f_n	Procedure I			Procedure II		
		d	e	K	d	e	K
1	357.97	2.060	13.62	167.16	1.97	14.60	174.65
2	196.21	1.116	3.96	172.26	1.10	5.04	173.79
3	148.15	0.787	3.00	184.43	0.80	2.06	182.61
4	201.83	1.108	4.90	177.73	1.20	4.38	164.54
5	298.54	1.675	9.49	172.56	1.70	8.55	170.58
6	256.85	1.482	6.44	168.96	1.42	8.42	174.65
7	175.41	—	—	—	1.03	2.60	168.74

*d, e and f_n are in *mm*. K is a dimensionless quantity.

TABLE II

Focal length results as obtained by two procedures

Lens No.	Focal length (mm)		$\frac{f-f_n}{f_n} \times 100$	
	Procedure I	Procedure II	Procedure I	Procedure II
1	370.62	355.31	3.5	−0.7
2	197.36	195.67	0.6	−0.3
3	139.39	140.70	−5.2	−5.0
4	196.92	212.34	−2.4	5.2
5	299.77	303.16	0.4	1.5
6	263.27	252.51	2.5	−1.6
7	—	181.10	—	3.2

It may be seen from Table II that generally the percent difference in focal length from nominal value obtained by any of the two procedures is within the tolerance limit specified in IS 988 : 1959. Small departures from this criterion obtained in case of lens 3 and 4 might be due to uncorrected nature of these doublets, as seen by star test, enabling only approximate measurement of 'd'. Results of the star test (Twyman, 1955) carried out to ascertain the qualitative performance of the lenses used are given in Table III

TABLE III

Appearance of star image

Lens No.	At best focus	In-focus	Out-focus	For oblique rays	Remarks
1	circular. first fringe bright and discontinous	Airy disc expands and pattern fades	outer rings bright, contra disc small	comatic flare, two systems of hyperbole mutually perpendicular at two foci (when the lens is racked to and fro)	Spherically over corrected, presence of coma and astigmatimsm indicated
2	circular, fringe surrounding Airy disc faint and discontinuous	Airy disc expands and pattern fades	slightly oval shaped-fringe pattern	comatic pattern	spherically corrected, presence of coma
3	oval shaped, right side ring bright andmassive	oval shaped	oval shaped. perpendicular to in-focus image	comatic pattern	uncorrected for spherical aberration, coma and astigmatism.
4	circular, first outer ring faint and discontinuous	outer rings fade	outer ring massive and bright	comatic pattern	spherically over corrected, uncorrected for coma
5	circular	outer rings massive. bright and slightly oval shaped	outer rings fade. slightly oval shaped perpendicular to in-focusimage	fringes rapidly fade	spherically under-corrected slight astigmatism
6	slightly oval shaped	pattern of rings seen	pattern of rings similar to in-focus image	fringes rapidly fade	spherically corrected, slight astigmatism
7	slightly oval shaped	oval pattern	Airy disc expands and fades	comatic pattern	spherically corrected, presence of coma and astigmatism

Assuming Gauss law to hold good, the error, δf, in measurement of f can be expressed as

$$\delta f = \pm\left[\left(\frac{\delta f}{\delta K}\right) \Delta + K^2\left(\frac{\delta f}{\delta d}\right)^2 \Delta d^2 + \left(\frac{\delta f}{\delta e}\right)^2 \Delta e^2\right]^{\frac{1}{2}}$$

Substituting the values of partial differential coefficients obtained from equation(i)

$$\delta f = \pm[d^2\Delta K^2 + K^2\Delta d^2 + \Delta e^2]^{\frac{1}{2}}$$

TABLE IV

Error in determination of focal length by two procedures

Lens No	Procedure I				Procedure II			
	$2.56\,d^2$	δf^2	$\pm\delta f$	$\pm\delta f\%$	$2.56\,d^2$	δf^2	$\pm\delta f$	$\pm\delta f\%$
1	10.86	13.86	3.72	1.04	9.89	12.89	3.57	1.00
2	3.19	6.19	2.48	1.26	3.09	6.09	2.46	1.25
3	1.59	4.59	2.14	1.44	1.64	4.64	2.15	1.45
4	3.14	6.14	2.45	1.22	3.68	6.68	2.58	1.28
5	7.18	10.18	3.19	1.07	7.40	10.40	3.22	1.08
6	5.62	8.62	2.93	1.14	5.16	8.16	2.85	1.10
7	—	—	—	—	2.71	7.71	2.77	1.58

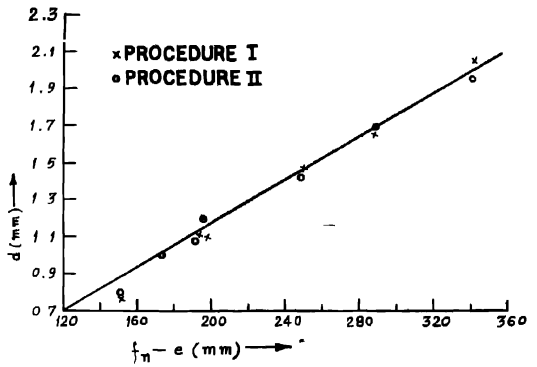

Fig. 2. d vs $(f_n - e)$ plot for different lenses.

As reported above the standard error in evaluation of K is ± 1.6. 'd' and 'e' can be assumed as accurate to within ± 0.01 and ± 0.05 respectively, being the least counts of respective verniers. **Hence,**

$$\delta f = \pm(3 + 2.56 d^2)^{\frac{1}{2}} \qquad \ldots \text{(iii)}$$

On this theoretical basis the average percent error in determination of focal length by procedures I and II comes out to be within ± 1.20 and 1.26 respectively (Table IV)

It may be pointed out, however, that from Table II, in case of procedures I and II, the average deviations of measured focal length from nominal value are 2.9 and 3.1 per cent respectively

It is felt that accuracy in focal length measurement by this method can be further improved upon by employing a biprism producing comparatively large angular deviation, and use of a two directional microscope capable of reading accurate to 0.01 mm in mutually perpendicular planes.

CONCLUSIONS

1 A method employing a biprism afflicted with small spherical refracting power is described which enables measurement of e f l of telescope lenses accurate to within ± 3 per cent It is considered suitable for inclusion in IS 988 : 1959

2 E f l. measurements were made following two independent procedures These yielded results of similar accuracy Procedure I is more rapid.

3 Accuracy in measurement diminished in case of uncorrected lenses

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